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## Simple Op-Amp Circuits

### OBJECTIVES:

To gain experience with design and construction of op-amp IC circuits, explore simple amplifier concepts and algebraic functional circuits, and further develop skills with the oscilloscope.

### BACKGROUND:

Refer to the class text, or any text on electronics, for basic information on the operational amplifier and descriptions of the standard inverting and non-inverting amplifier configurations. Although most op-amp circuits can be understood based on the characteristics of an ideal op-amp, in the lab we will use real op amps with non-ideal characteristics. In this experiment we will encounter two of these: output saturation and finite slew rate. Output saturation simply means the op amp cannot force the output voltage beyond the voltage range it is supplied with. We will be supplying the op amp with +/- 15V. As you will find, the op-amp will not be able to swing above +15V or below -15V.

An additional non-ideality that can often show up with amplifier circuits is unwanted oscillation. If you see occasional bursts of something on the oscilloscope trace for the op-amp output, call it to the attention of the TA; you may need to add bypass capacitance to the power supply pins (not intended to be part of this experiment, and therefore not explained further here).

Note: In the circuits below the pin numbers for the various op amp connections are shown. Pins not shown are to be left unconnected.

### PROCEDURE:

#### Part 1. Op-Amp Circuit Construction; Unity-gain buffer amplifier

The op-amp circuits are the only type of *active* circuit that we will encounter in ECE 2A. Active circuits require an external source of energy to operate properly. Figure 1 below shows a picture of the LM741 op-amp that we will use, with the pin numbers conventionally labeled (for more detail, a copy of the LM741 data sheet is posted at the class web site). Most op-amps have the same pin configuration. Use the +/-20V outputs of your bench power supply, adjusted appropriately, for the +/- 15V sources.

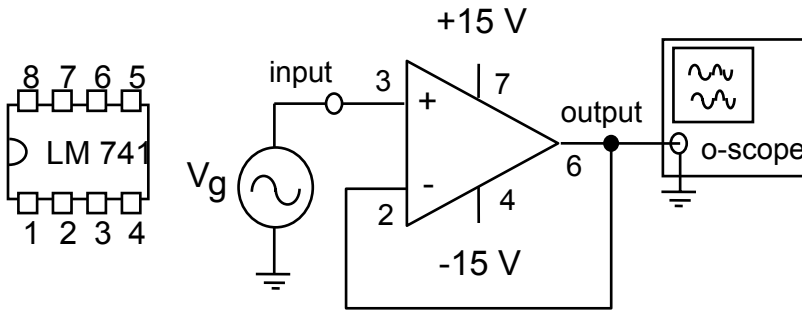


Fig 1: Op-amp IC pin diagram and test-circuit schematic

(1) Using your breadboards and the lab bench power supply, construct the circuit shown in figure 1 above. This is called the *voltage follower* configuration, and is a type of *buffer* amplifier. It is often used because the high input impedance prevents excessive loading of the source generator; i.e., no current is drawn from the source, therefore no voltage drops on any internal resistance of the source. Use your alligator clip leads to connect the breadboard to the power supply terminals. Figure 2 indicates how this circuit could be laid out on your breadboard. Also remember that we want the common terminal (COM) of the power supply to be at ground potential. It will be useful if you pick a row of sockets to be used for all ground connections.

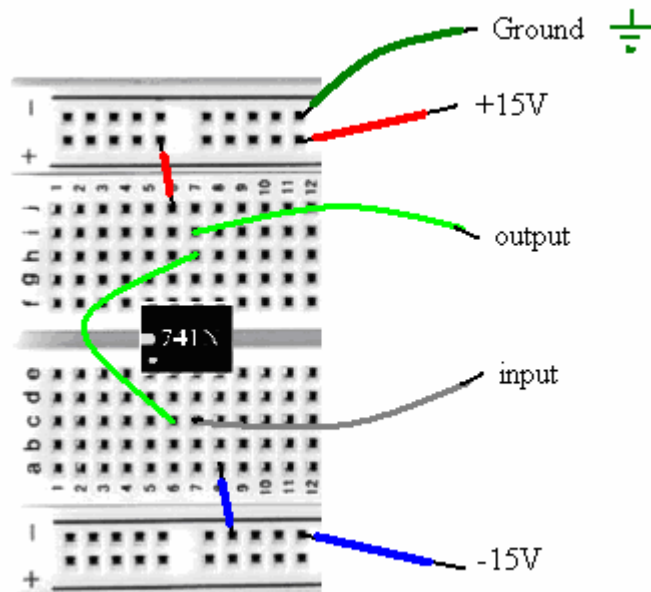


Fig. 2 Breadboard layout of fig 1

(2) Use the function generator at the bench as source  $V_g$  to provide a 1V amplitude (2V pk-pk), 1kHz sinewave excitation to the circuit, and observe the output on the oscilloscope. Set up the scope so that the input signal is displayed on channel 1, and the output signal is displayed on channel 2. Make a plot of the two waveforms in your lab notebook. What is the voltage gain of this circuit? Is it an inverting or non-inverting amplifier?

(3) Adjust the input signal amplitude and frequency. The output should follow the input signal precisely for most input signals. However, in reality the output signal does not respond instantaneously to the input signal. This non-ideality can be observed when the input signal is a rapidly varying function of time. Set the function generator to a square wave signal and increase the frequency until you see a departure from ideal behavior. You will probably need to adjust the time scale (Sec/Div) to see this. At approximately what frequency does this occur? Make a plot of the output waveforms at a frequency above this point, and measure the rise time. Also note the peak-to-peak voltage of the output signal.

(4) Continuing to use the square wave input, lower the frequency back to 1kHz, but leave the time scale and triggering as you had it for the measurement of step 3. Is the rise time of the op-amp still the same? Now adjust the time scale to where you can see several periods of the waveform. You should learn from this that the output rise time is limited, regardless of frequency, but it is less noticeable at lower frequencies.

## **Part 2. Inverting Amplifier**

- (1) Assemble the inverting amplifier circuit shown in figure 3. Remember to shut off the +/-15 V supply before assembling a new circuit. Use the decade resistor box for the 4.7k $\Omega$  resistor. Note that there are additional connections to ground in this circuit.
- (2) Apply a 1 Volt amplitude, 1kHz sine wave at the input, and display both input and output on the oscilloscope. Measure the voltage gain of this circuit, and compare to the theory discussed in class. Make a plot of the input/output waveforms in your notebook.
- (3) Increase the feedback resistance from 4.7k $\Omega$  to 10k $\Omega$  . What is the gain now? Slowly increase the amplitude of the input signal to 2 Volts. What happens? Describe and draw waveforms in your notebook. Can you explain this behavior?

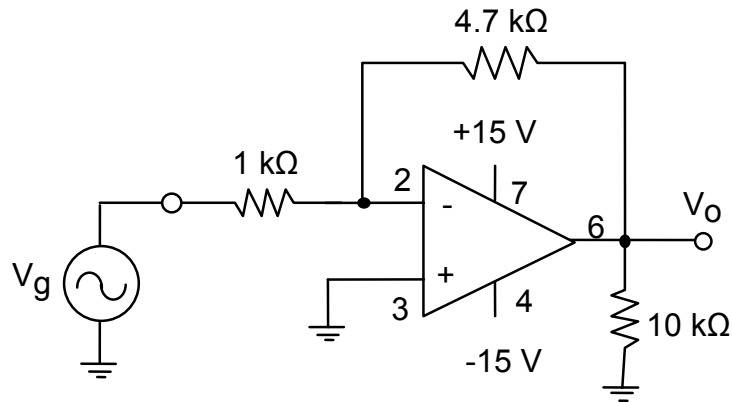


Fig 3: Inverting amplifier schematic

### Part 3. Summing Circuit

- (1) With the power off, modify your inverting amplifier circuit as shown in figure 4. Use the +18V output of the power supply for  $V_{dc}$ . Turn the +18V output all the way down, so that you can adjust up from zero. This circuit behaves like an inverting amplifier with two inputs. What is the ideal relationship between the output voltage and the inputs  $V_g$  and  $V_{dc}$ ?
- (2) Apply a 1 Volt amplitude sinewave for  $V_g$  and 2 Volt DC source for  $V_{dc}$ . Observe and record the input/output waveforms on the oscilloscope screen. Pay close attention to the ground signal level of the output channel on the oscilloscope screen (note: make sure both channels are set for DC coupling). When used in this way, such a circuit could be called a *level shifter*.
- (3) Pull out the DC offset knob of the function generator and adjust the DC offset until  $V_o$  has zero DC component. Confirm this either by measuring  $V_o$  with a DC voltmeter, or by verifying on the oscilloscope that  $V_o$  swings equally above and below ground. What must the DC offset of the function generator be? Can you confirm this with a measurement?
- (4) Push the DC offset knob back in to reset the offset to zero. With channel 2 of the scope (the channel connected to the op-amp output) set for 5V/div, turn up  $V_{dc}$  slowly to +18V. What happens to  $V_o$ ? Record the DC voltage of the output.
- (5) Return  $V_{dc}$  to approximately +2V. Set the scope to 1V/div, AC coupled, and adjusted so you can see the complete  $V_o$  waveform. Turn  $V_{dc}$  back up to 18V. What does the oscilloscope trace for  $V_o$  look like? Does the amplifier appear to be amplifying? Now raise your right hand and say the following out loud:

I solemnly promise I will never tell the TA my amplifier isn't amplifying without first using DC coupling to verify that the output is not saturated.

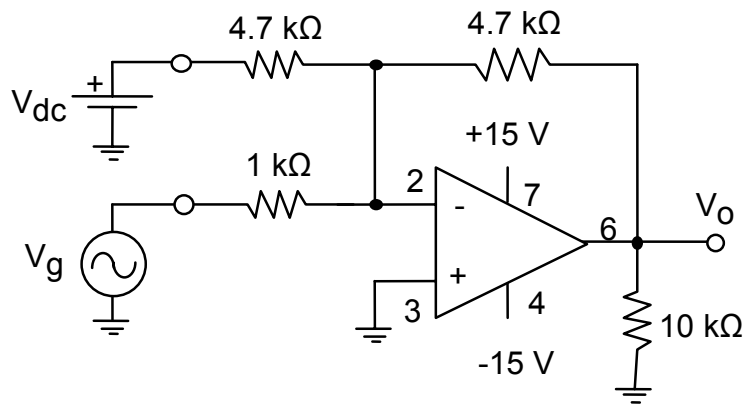


Fig 4: Op-amp summing circuit

#### Part 4. Non-inverting amplifier

- (1) Assemble the non-inverting amplifier circuit shown in figure 5. Remember to shut off the +/-15 V supply before assembling a new circuit. Use the decade resistor box for the feedback resistor & the 1k resistor between pins 6 and 2).
- (2) Apply a 1 Volt amplitude, 1kHz sine wave at the input, and display both input and output on the oscilloscope. Measure the voltage gain of this circuit, and compare to the theory discussed in class. Make a plot of the input/output waveforms in your notebook.
- (3) Increase the feedback resistance from 1kΩ to 9kΩ . What is the gain now?
- (4) Increase the feedback resistance further until the onset of clipping, that is, until the peaks of the output signal begin to be flattened due to output saturation. Record the value of resistance where this happens? Increase the feedback resistance to 999kΩ. Describe and draw waveforms in your notebook. What is the theoretical gain at this point? How small an input signal would be required to produce a 10V amplitude sine wave at the output, given this gain? Try to adjust the function generator to this value. You may need to use the 0.2V button on the function generator, which reduces the output amplitude. Describe the output achieved.
- (5) Increase the amplitude of the function generator back to 1V and then disconnect the feedback resistor completely. The op-amp is now running "open-loop". Op amps used in this configuration are referred to as "voltage comparators". The output can assume one of only two states (voltage levels), which reflect a comparison of the input voltages. To see this, complete the following statement for this circuit:

When  $V_g > \underline{\hspace{2cm}}$ ,  $V_o = \underline{\hspace{2cm}}$ ; when  $V_g < \underline{\hspace{2cm}}$ ,  $V_o = \underline{\hspace{2cm}}$ .

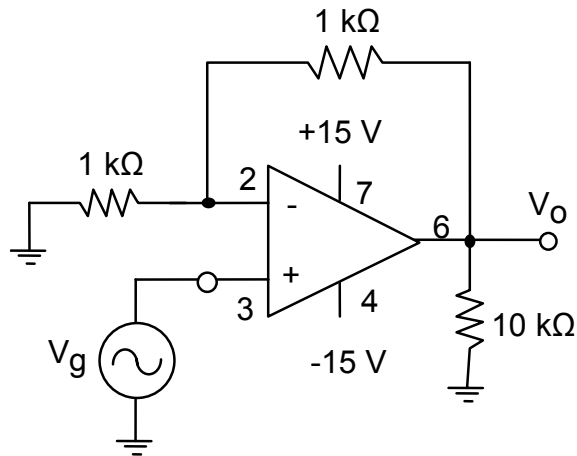


Fig 5: Non-inverting amplifier circuit

### Discussion Questions

1. In part 1, step 3, you found the maximum rate the op-amp output could change. This is specified on the data sheet as the "slew rate", and has units of Volts/microsecond. Calculate the slew rate you observed from

$$\text{Slewrate} = \frac{\Delta V_{10-90}}{\text{rise\_time}}$$

Is this greater than or equal to the guaranteed minimum from the data sheet ?

2. The DC voltage you recorded in part 3, step 4, is the output saturation voltage. Is your measured value within the limits specified on the data sheet? The relevant spec in the Fairchild data sheet is "Output Voltage Swing"  $V_{o(p-p)}$ , and our condition corresponds to  $V_{cc} = \pm 15V$ ,  $10k\Omega$  RL.

3. The +/-voltage supplies, commonly labeled  $V_{cc}$  and  $V_{ee}$ , are also referred to as the power rails. Can you guess what the output voltage swing would be for an op-amp advertised as being a "rail to rail" op amp?